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TECHNICAL NOTE

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STATIC FORCE TESTS OF SEVERAL ANNULAR JET CONFIGURATIONS

IN PROXIMITY TO SMOOTH AND IRREGULAR GROUND

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SUMMARY

The present investigation was undertaken to determine the effects of changing the plan form from circular to elliptical and the effects of irregularities in the ground on the thrust augmentation of a discontinuous annular jet in ground proximity at zero forward speed.

The results indicate that appreciable thrust augmentation can be obtained with a discontinuous annular jet but the augmentation decreases with increasing percentage of open area in the jet curtain. Thrust augmentation is obtained with elliptical plan forms but this augmentation is less than that of a circular plan form of the same circumference. Surface irregularities decrease the thrust augmentation with the jet very close to the ground.

INTRODUCTION

Recent work (refs. 1 to 4, for instance) has focused attention on the thrust augmentation of an annular jet. At zero forward speed the thrust experienced by an annular jet can be considerably greater than the momentum of the air being ejected from the jet at heights above the ground equal to a small fraction of the overall diameter of the annulus. This added thrust results from the above ambient pressure of the air trapped between the center body and the ground by the curtain of high-velocity air from the annulus. As pointed out in reference 3, the curtain of air must curve outward as it approaches the ground. The centrifugal force imparted to the curving jet balances the pressure buildup under the base. Thus, as the device is brought closer to the ground, the curvature of the curtain must increase with an accompanying increase in the pressure on the base and the resulting increase in total thrust.

The present exploratory investigation was undertaken to study some effects of variables in the jet geometry on the thrust augmentation in proximity to the ground at zero forward speed. Of particular interest was the determination of the effect of having an incomplete curtain and the effect of elliptical plan forms. Some effects of irregularities in ground surface are included.

SYMBOLS

T	thrust, lb
h	height above ground, ft
D	outside diameter of annulus, ft
A_b	nozzle base plate area
C	circumference of annulus, ft
A_j	jet flow area
z	depth of trench or cliff, ft

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Subscripts:

m	measured
c	calculated
∞	ground board removed

MODEL AND APPARATUS

The general arrangement of the apparatus is shown in figure 1(a). The annular jets (fig. 1(b)) were made by silversoldering 12 individual nozzles to the periphery of a steel plate of desired plan form. This construction made it relatively easy to change the plan form or to change the spacing of the air nozzles. The 12 nozzles were made by flattening the ends of pieces of 3/4-inch-diameter tubing to form 1/16-inch-wide slots. The resulting slots were $1\frac{3}{64}$ inches long and had a cross-sectional area about one-eighth that of the basic tube. Twelve of these nozzles silversoldered to the periphery of an approximately 5-inch-diameter plate produced an annular jet made up of 12 jets occupying 80 percent of the periphery and 12 open gaps comprising

20 percent of the periphery. For convenience the jet configurations are identified by the percentage of open periphery. The above example is referred to as a 20-percent open nozzle.

High-pressure air was fed to the individual nozzles by 12 plastic tubes which were connected to a plenum chamber. The entire assembly was mounted on a strain-gage balance, as shown in figure 1(a), so that thrust could be measured. Air was fed to the plenum chamber by long flexible hoses oriented so that they did not affect the thrust readings.

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The calculated momentum thrust of the nozzles was determined from the measured mass flow and jet velocity by the expression

$$T_c = wV_j$$

where w is the mass flow in slugs/sec and V_j is the jet velocity in ft/sec calculated from the jet total pressure assuming isentropic expansion to atmospheric pressure. All tests were restricted to ratios of nozzle total pressure to atmospheric pressure of about 2.0.

The total pressure of the air ejected from the jet with the ground board in place was determined from a static-pressure measurement in one of the 3/4-inch-diameter tubes. To determine the feasibility of using only one tube to measure the total pressure, the total-pressure distribution of the air jets was surveyed with a small pitot tube with the ground board removed. The mass flow was measured with a standard sharp-edge orifice plate flow meter located in the incoming line.

The ground was simulated by a sheet of plywood approximately 3 feet square which could be easily moved with respect to the nozzle. The trench and cliff were simulated by adding blocks of the desired thickness to the plywood ground board.

RESULTS AND DISCUSSION

The zero-forward-speed characteristics of the present circular configuration are compared with the results for configuration A $\left(\text{continuous annulus, } \frac{A_j}{A_b} = 0.31\right)$ of reference 1 and some unpublished data $\left(\text{continuous annulus, } \frac{A_j}{A_b} = 0.04\right)$ in figure 2. The results are presented in two forms: the ratio of thrust at a particular height to the measured thrust with the ground board removed $T_{m,h}/T_{m,\infty}$ (fig. 2(a)) and the ratio of the measured thrust to calculated momentum thrust of a circular nozzle T_m/T_c

(fig. 2(b)). The second form T_m/T_c is preferred because the base losses are accounted for, as shown by the fact that the ratio is considerably less than 1 at $\frac{h}{D} = \infty$.

Several differences between the results obtained in the present investigation and those for configuration A of reference 1 are apparent in figure 2. The present data indicate a hump in the curve at a height of about 0.4D which was not present in the data of reference 1. Also, the discontinuity in the curve of reference 1 at a height of 1.6D could not be found in the present investigation although special care was taken to locate such a discontinuity. Further, loss in thrust out of ground effect due to suction pressures on the base is much greater with the present configuration. All these differences in the results are apparently due to the difference in the ratio of jet area to base area. Comparison of the data of the present investigation with the results of the unpublished investigation using approximately the same ratio of jet area to base area indicates little difference between a continuous and the 20-percent open discontinuous curtain. (See fig. 2(b).)

The effect of increasing the percentage of open area in the jet curtain is shown in figure 3. These results were obtained by cutting off the supply of air to appropriate nozzles as indicated in figure 3. Thus, the gap size was not consistent for all the arrangements shown. Large increases in the percentage of open area in the jet curtain decreased the augmentation factor appreciably.

There are some basic differences between the flow phenomena observed on the present discontinuous-curtain configuration and that observed with a continuous curtain. With a continuous curtain the high-velocity exhaust must be deflected outward as it approaches the ground. The pressure between the base plate and the ground is exactly balanced by the centrifugal force on the jet sheet as it is deflected outward. With the 20-percent open annulus the jet sheet was not deflected outward but, within the range of heights tested, impinged on the ground board directly below the jet exits. When an air jet strikes a surface perpendicular to it, the jet spreads equally in all directions. Thus, a considerable part of the exhaust from the 20-percent open annulus was deflected inward between the base plate and the ground board. It could escape again, however, through the open places in the jet curtain. These open places, however, act as orifices and the flow through them experiences a pressure drop resulting in an increase in pressure of the air trapped beneath the model. Thus, even an incomplete annular curtain is capable of containing a pressure and producing a thrust augmentation.

Effect of Plan Form

A comparison of the results obtained at zero forward speed with those of discontinuous jets of circular and elliptical plan forms is presented in figure 4. For these tests the elliptical jets were built to have the same circumference as the circular jet so as to maintain the same momentum thrust for all nozzles. Some loss in thrust augmentation results from distorting the circular plan form into an ellipse partly, at least, because of the reduction in plan-form area. However, appreciable augmentation is obtained even with a 4-to-1 elliptical plan form with the jet very close to the ground. It should be noted that, because the mass flow through the nozzles was not measured in these tests, the results are presented as the ratio of thrust to measured thrust at $\frac{h}{D} = \infty$.

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Effects of Irregularities in Ground

The effects at zero forward speed on the thrust augmentation of a discontinuous annular jet over a partially elevated surface simulating a cliff are shown in figure 5. Even the minimum discontinuity tested (0.1D) resulted in some loss in augmentation with the jet very close to the ground.

The limited data available here indicate that the surface irregularities will have to be very small with respect to the nozzle diameter if appreciable thrust-augmentation factors are to be realized. Additional investigations with smaller irregularities and with the nozzle closer to the ground than in the present investigation will have to be made before the limiting amount of surface irregularity can be defined.

CONCLUSIONS

The results of the present investigation of the characteristics of discontinuous annular jets at zero forward speed indicate the following conclusions:

1. Appreciable thrust augmentation can be obtained in ground proximity with a discontinuous annular jet. Increasing the percentage of open area in the jet curtain, however, decreased the thrust augmentation.

2. Changing the plan form of the discontinuous jet from circular to elliptical, with the same circumference, decreased the thrust

augmentation somewhat; however, appreciable thrust augmentation was obtained even with a 4-to-1 elliptical plan form with the jet very close to the ground.

3. Irregularities in the surface of the ground reduced the thrust augmentation with the jet very close to the ground.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 21, 1959.

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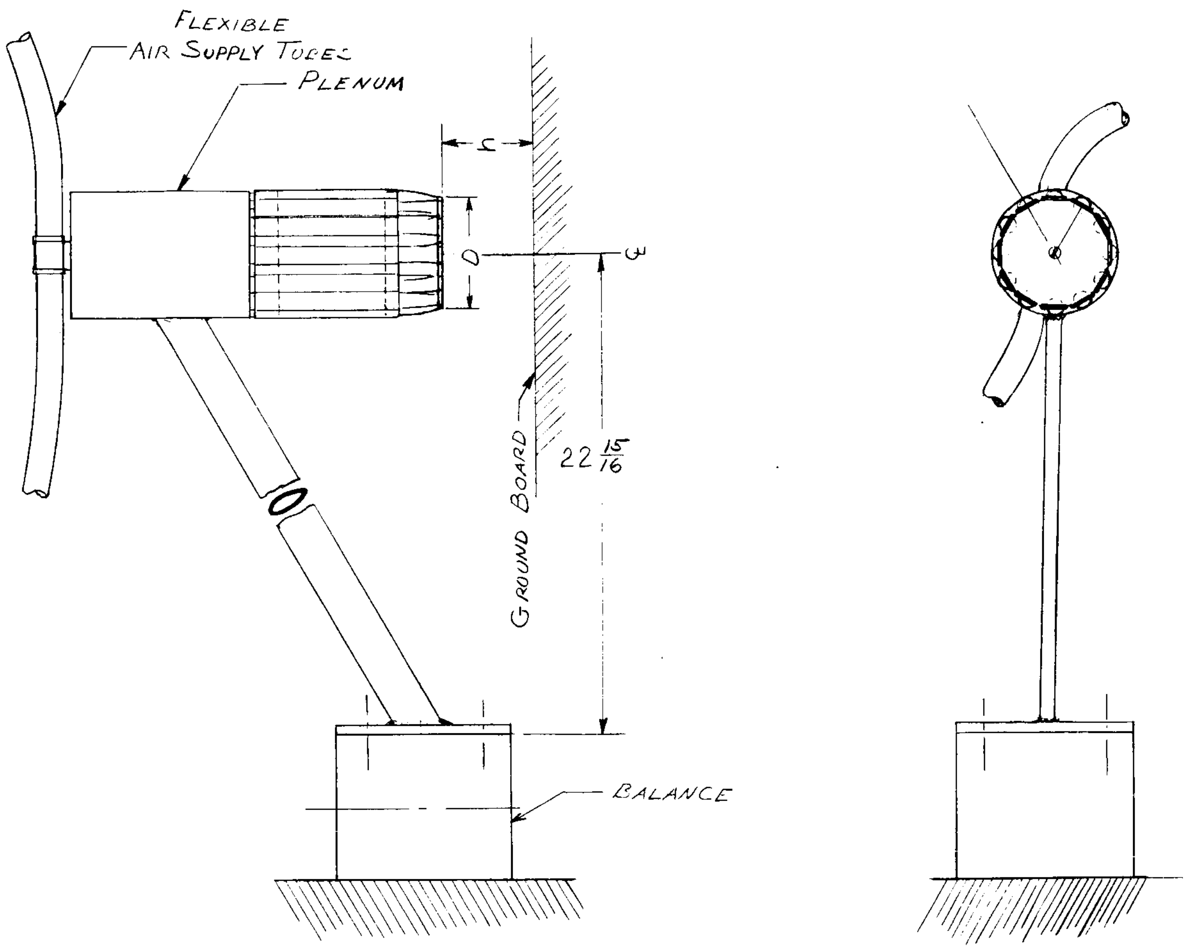
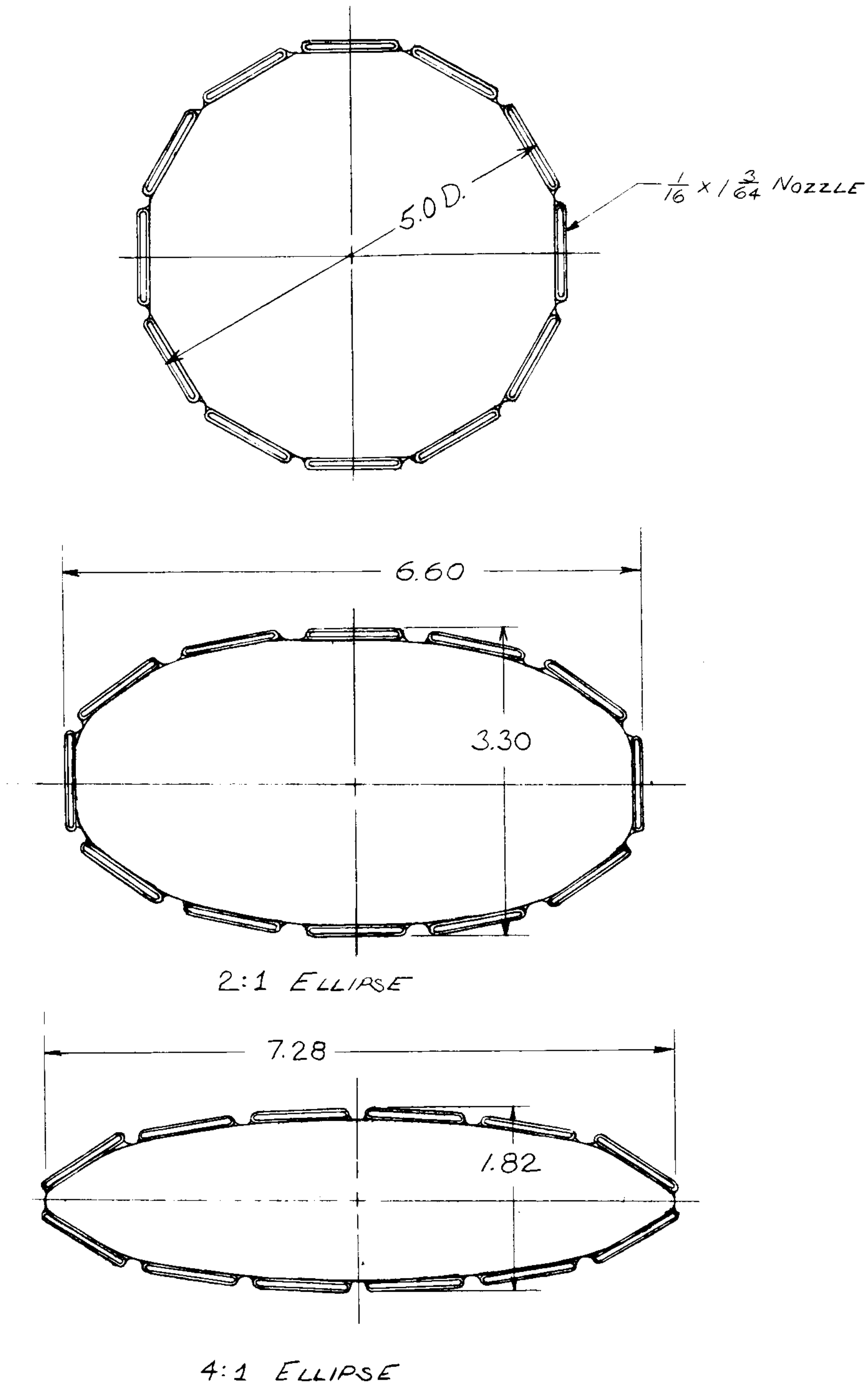


(a) General arrangement.

Figure 1.- Arrangement of model. All dimensions are in inches.



(b) Plan forms studied.

Figure 1.- Concluded.

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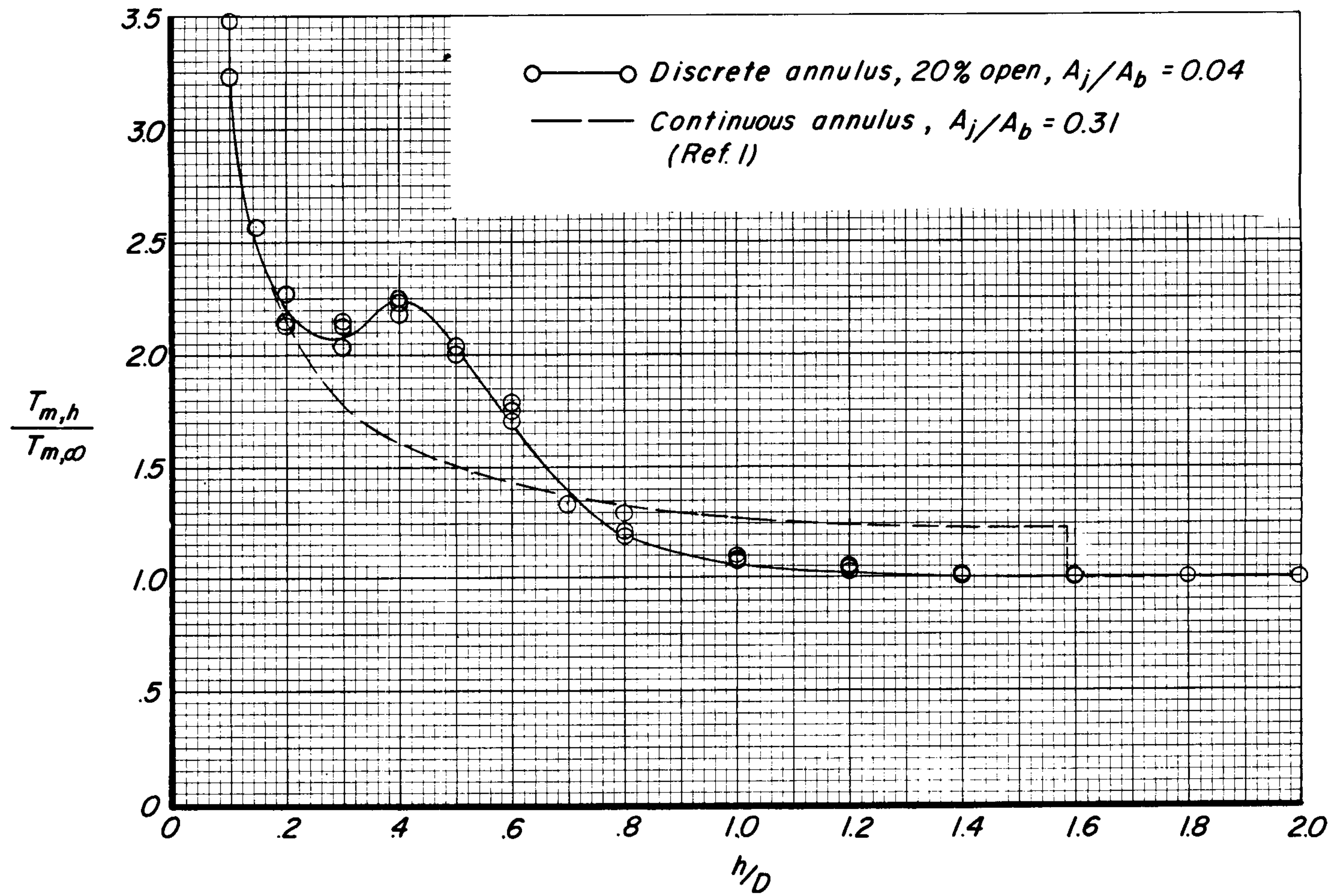
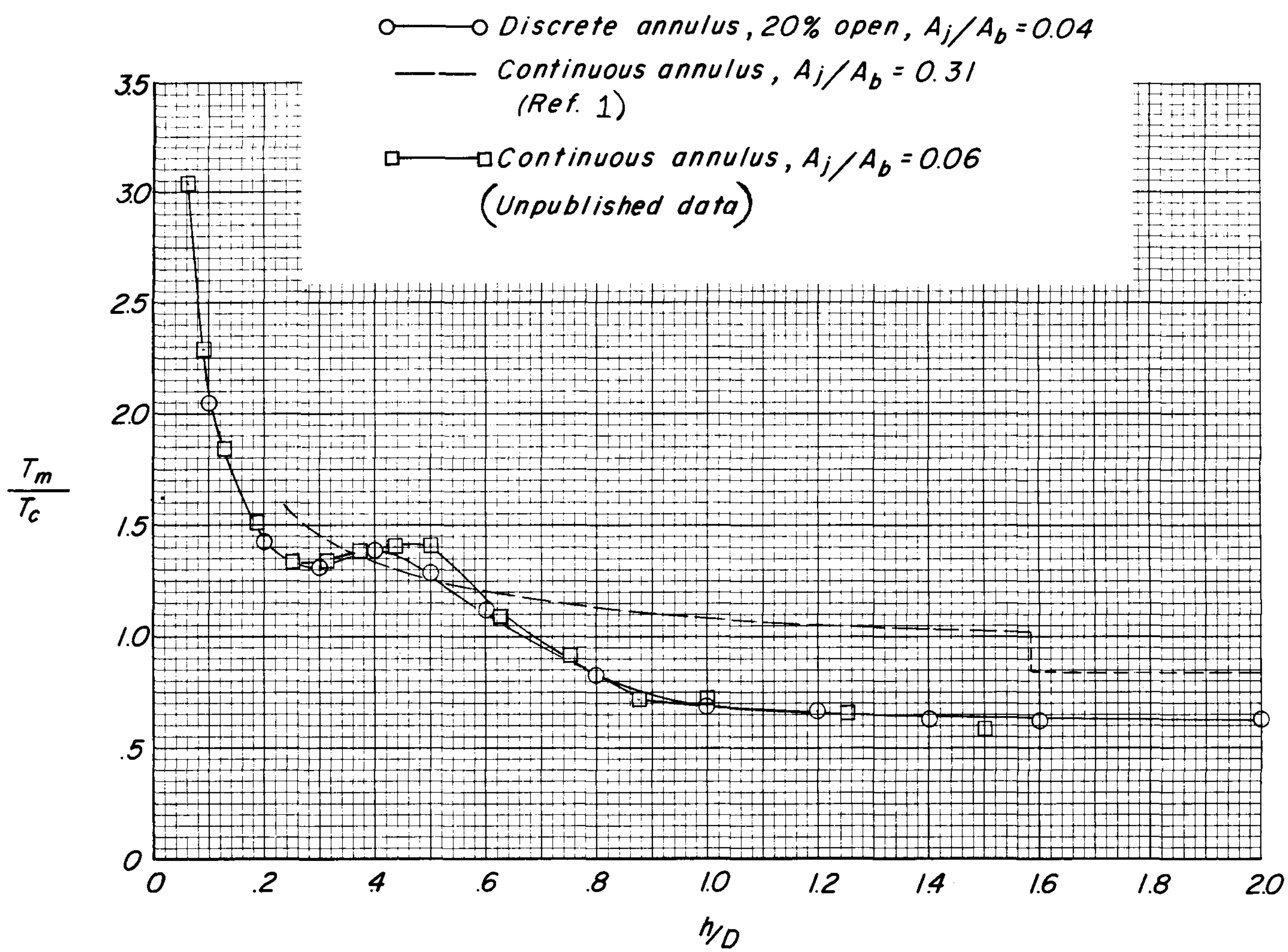


(a) Variation of $T_{m,h}/T_{m,\infty}$ with h/D.

Figure 2.- Basic characteristics of the 5-inch circular annular jet (12 nozzles) at zero forward speed.



(b) Variation of T_m/T_c with h/D.

Figure 2.- Concluded.

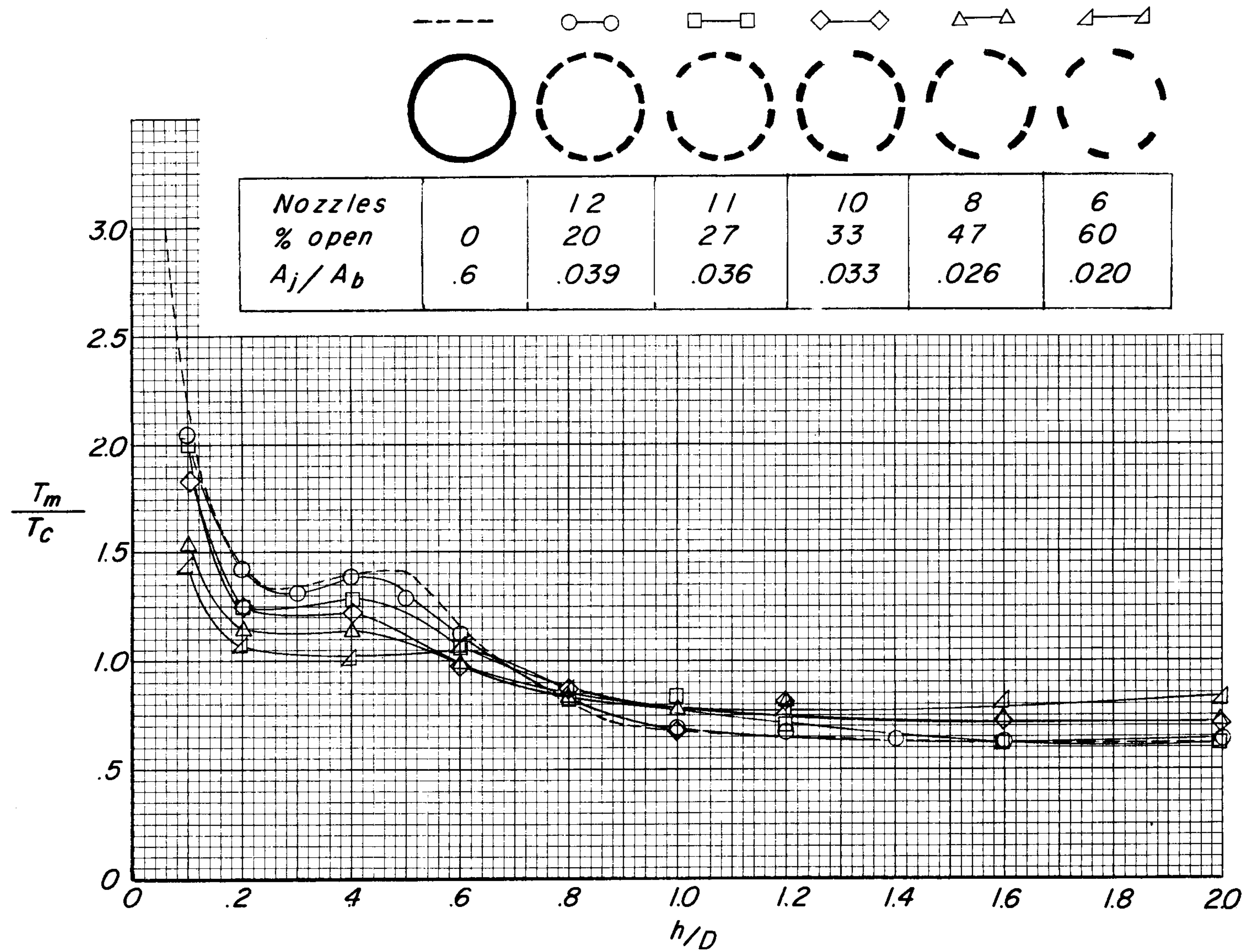


Figure 3.- Effect of change in jet curtain continuity on the zero-forward-speed characteristics of a circular annular jet.

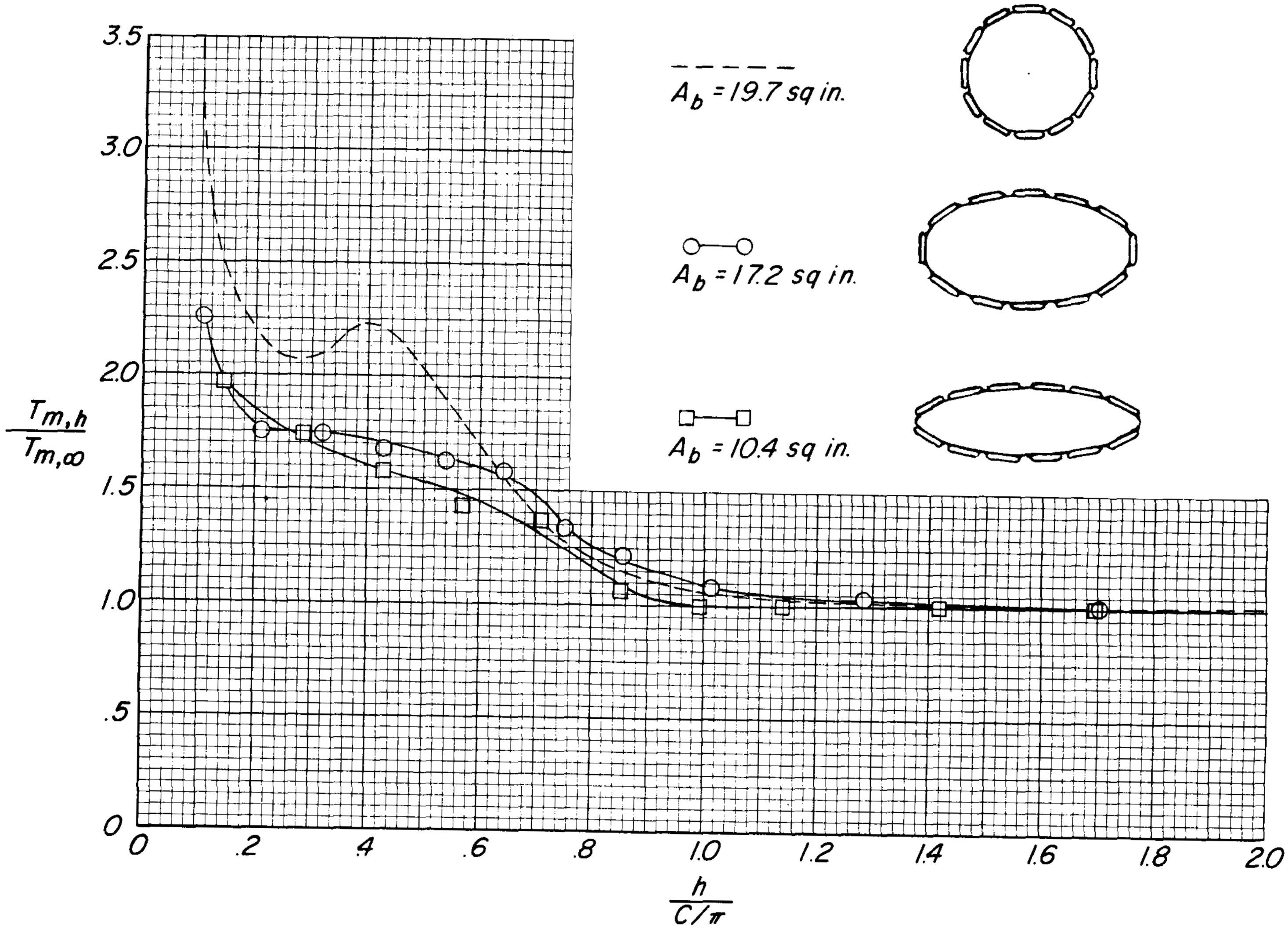


Figure 4.- Effect of change in shape on zero-forward-speed characteristics of annular jets. 12 nozzles; 20-percent open nozzle.

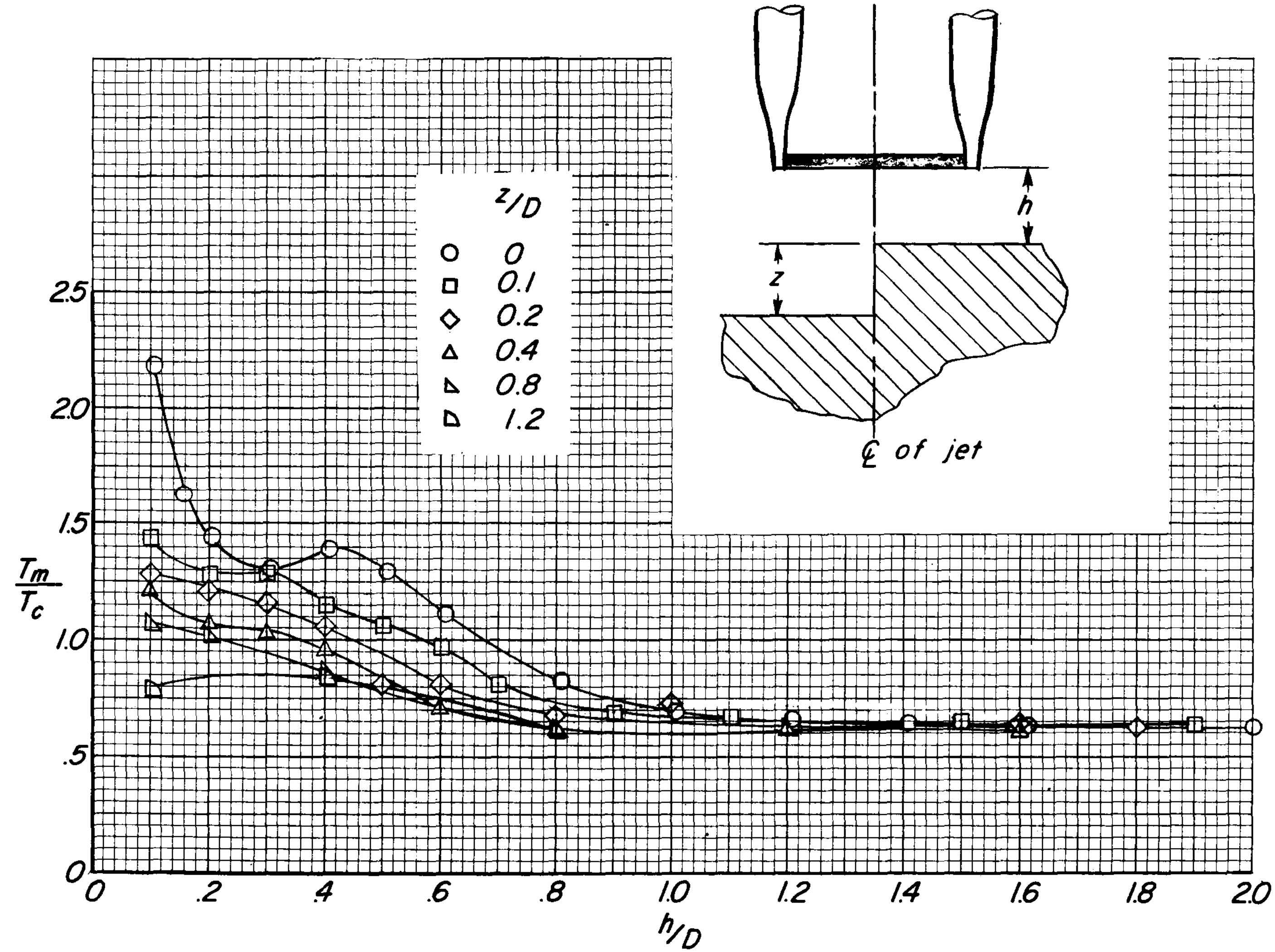


Figure 5.- Characteristics of a discontinuous circular annular jet with 12 nozzles (20-percent open nozzle) over the edge of a cliff at zero forward speed.